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Digital for real: A multicase study on the digital transformation of companies in the embedded systems domain

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Abstract

With digitalization and with technologies such as software, data, and artificial intelligence, companies in the embedded systems domain are experiencing a rapid transformation of their conventional businesses. While the physical products and associated product sales provide the core revenue, these are increasingly being complemented with service offerings, new data-driven services, and digital products that allow for continuous value creation and delivery to customers. However, although there is significant research on digitalization and digital transformation, few studies highlight the specific needs of embedded systems companies and what it takes to transform from a traditional towards a digital company within business domains characterized by high complexity, hardware dependencies, and safety-critical system functionality. In this paper, we capture the difference between what constitutes a traditional and a digital company and we detail the typical evolution path embedded systems companies take when transitioning towards becoming digital companies.

KEYWORDS

business models, continuous value delivery, digital transformation, digitalization, embedded systems

1 | INTRODUCTION

For decades, companies in the embedded systems domain have successfully focused their value-creating activities on physical products involving primarily mechanics and electronics components. In domains such as telecom, automotive, defense, security, and manufacturing, product sales have been, and currently are, where the primary revenue is generated. Although most companies have some service offerings that allow for more frequent or at least periodic relationships to customers, the revenue generated from these services is still secondary. Often, maintenance services are offered at scheduled intervals and sold as part of the overall product transaction but without having a separate revenue model associated to them. In such models, the focus is on the short-term selling of products rather than the long-term and continuously evolving customer needs.[1,2]

However, with technologies such as software, data, and artificial intelligence (AI) being introduced, new opportunities arise. From developing products consisting of primarily hardware and with software playing a minor role, embedded systems companies are in the midst of complementing their physical products with software-driven services and solutions that extend, and fundamentally change, previous product offerings[3] as well as the turnaround time of these products. In these new service-oriented offerings, software is one of the enablers for digital offerings in which data and AI technologies also play an increasingly critical role. As previously reported, this involves not only a change of revenue models and value creation opportunities but also a fundamental shift in the relationship to customers and the response time to market needs.[1,4] In particular, companies are exploring the potential with frequent updates of software, real-time collection of customer and product data, and opportunities related to continuous improvement and customization of products.[3,5,6] Instead of having products deteriorate over time, companies seek to improve product performance and customer experience with new features and functionality being added to the system on a continuous basis. This means a shift in value creation and revenue as well as in customer relationships and experience.[7] In marketing, this shift is typically referred to as relationship marketing in order to emphasize the relational elements, the multiple stakeholders, and the more collaborative relationship between buyers and sellers.[4] In the software engineering field, similar patterns are reported and described. In our previous research,[8] we present a model for strategic ecosystem management in which the collaboration and value co-creation between multiple stakeholders is emphasized. In our previous work,[9] we discuss collaborative innovation and how to select the optimal collaboration strategy considering the innovation at hand as well as the collaborative and/or the competitive relationship between stakeholders. And whereas Manikas and Hansen[10] provide an overview of software ecosystems and how to effectively benefit from these, Bosch[11] outlines how digital technologies are rapidly changing large-scale software engineering and how traditional value creation is being complemented, and even replaced, with new and more continuous revenue streams.

In our previous work, we studied embedded systems companies and how the business ecosystems in which they operate are rapidly changing due to digitalization.[3] In this work, we focused on how customer needs evolve when new technologies are introduced, how ecosystems transform due to digital technologies, and how traditional technologies commoditize over time. Based on our findings, we developed a decision framework that captures technical aspects of digitalization as well as alternative strategies that incumbents can use to avoid disruption. Also, in an earlier study, we compared data management practices in embedded systems companies with similar practices in Internet of Things (IoT) companies and in online companies concluding that many of the embedded systems companies lack mechanisms for effective use of the data they collect.[5] Although this study was conducted a few years back, the findings highlight challenges that remain relevant and that need further attention because data are becoming an increasingly important asset for companies. However, despite our own and others' previous attempts, and to the best of our knowledge, there is limited research on what it involves for embedded systems companies to transition from a traditional company with value being created from product sales towards becoming a digital company with complementary digital and service-oriented offerings. In addition, little is known about the transition towards, and the implications of, a continuous customer relationship in which the lifetime of a product is significantly extended and in which customer value is created throughout the lifetime of a product. Therefore, this paper takes more of a business model and value creation perspective when exploring how companies in the embedded systems domain are transitioning from being traditional companies towards becoming digital companies. In contrast, and to complement previous work, we focus our research on the following:

- How are companies in the embedded systems domain complementing their traditional, and primarily transactional, models for value creation with models based on continuous value delivery to customers and what is the typical process for achieving this?
- What are the steps that companies in the embedded systems domain take when evolving towards becoming digital companies in which revenue is generated from products and services but increasingly also from data and other digital assets?
- What are the key challenges that companies in the embedded systems domain experience when transitioning from traditional towards digital companies and how can these be addressed in future research?

The contribution of this paper is threefold. First, we explore how digitalization transforms companies in the embedded systems domain, and we capture the difference between traditional and digital companies. Second, we present a model in which we detail the typical evolution path companies take when transitioning from traditional towards digital companies. In this model, we outline four orthogonal dimensions in which companies need to evolve and that are critical for this transition to be successful. These dimensions are (1) the product upgrade dimension, (2) the business model dimension, (3) the data exploitation dimension, and (4) the AI/machine learning (ML)/deep learning (DL) dimension. Third, we identify open research questions that need to be addressed in future research to help companies further advance their digital transformation. The research questions we identify are grouped into eight categories, that is, business models, business ecosystems, data, system architecture, R&D process, organization, and culture, and represent the key topics of interest for future research in the area of digital transformation. With these contributions, we intend to support practitioners in the digital transformation in which they are part as well as encourage the research community to engage in solving what we identify as key challenges in this field of research.

The remainder of this paper is structured as follows. In Section 2, we review contemporary literature on digitalization and digital transformation. In Section 3, we describe the research method that was adopted in the study and we present the case companies. In Section 4, we present the empirical findings. In Section 5, we discuss our findings and we present our conceptual contributions. In Section 6, we identify open research challenges for future research. In Section 7, we review related work. In Section 8, we conclude the paper.

2 | BACKGROUND

2.1 | Digitalization and digital transformation of businesses

Digital technologies have fundamentally changed the ways in which we do business. With new ways to connect, collaborate, and compete, and with sophisticated technologies allowing for vast amounts of data to be collected, processed and executed upon, companies of today are facing a situation in which business opportunities emerge more rapidly than ever before. In business, digitalization typically refers to enabling, improving, and transforming business operations, business functions, business models, and business processes, by leveraging digital technologies.[2] During recent years, the phenomenon of digitalization has been extensively studied across research disciplines and with prominent studies in areas such as management, information systems, marketing, and software engineering. Although the research scope and focus vary between different research disciplines, they all highlight the challenges, the opportunities, and the radical impact of new digital technologies. In particular, attention is paid to the many ways in which digital technologies enable novel business models,[12,13] transform and disrupt existing business ecosystems,[3,14,15] support process improvement,[16] improve customer experience,[17,18] and facilitate innovation and new value creation.[19,20] In addition, there are studies highlighting how digital transformation of businesses impacts organizational culture and infrastructure[16,21] as well as how the characteristics of digital technologies give rise to opportunities that did not exist in the past.[22] Moreover, research shows how new technologies increasingly influence the choice of a particular business model[23,24] and that what we experience today is a shift of attention away from matters internal to the firm towards what happens beyond its boundaries and in the relationship to its customers and partners.[7,25,26]

There are numerous definitions of what constitutes digital transformation. When searching for "digital transformation" on Google,[27] it is defined as the "profound and accelerating transformation of business activities, processes, competencies and models to fully leverage the changes and opportunities of digital technologies and their impact across society in a strategic and prioritized way." In Bowersox et al.,[28] digital transformation is described as the "process of reinventing a business to digitize operations and formulate extended supply chain relationships," and the authors emphasize the importance of utilizing the potential of new technology across the total supply chain. In Mazzone,[29] digital transformation is described as the "deliberate and ongoing digital evolution of a company, business model, idea process, or methodology, both strategically and tactically," and the author recognizes the multifaceted and multidimensional impact of this process. As yet another example of this, the definition by Schallmo et al.[30] includes the networking of actors such as businesses and customers across all value-added chain segments to highlight the impact digital transformation has on the business ecosystem, the relationship to partners, and on current and future value propositions. In relation to this, the authors recognize the importance of data when claiming that successful digital transformation requires skills that involve the extraction and exchange of data among partners as well as the analysis and conversion of these data into actionable information. In our previous work and based on multicase study research in embedded systems companies,[3] we view software, data, and AI as enablers for digitalization. These technologies offer a range of new capabilities and opportunities to extend existing product offerings as well as to create new product and service offerings to customers. Although the definitions mentioned above originate from different research disciplines, they all recognize that the application of new digital technologies is at the core of digital transformation. In addition to being a critical means to increase operations and performance, they work as enablers to increase reach and relationships within and outside a company and with the capacity to help companies reinvent their existing value chains and revenue streams.[31–33]

2.2 | Digital transformation of embedded systems companies

In the embedded systems domains, software is rapidly becoming the central differentiator for many products, whereas mechanics and electronics are becoming commodities.[3,5,11] With functionality implemented in software rather than in hardware, companies can more frequently update and continuously improve the product also after manufacturing and deployment at the customer and extend the lifetime of a product as well as the experience of the customer. As enablers for digitalization, software, data, and AI technologies bring a number of opportunities in terms of connectivity, automation, and frequent deployment of functionality. During recent years, and as reported in a number of studies, continuous integration and continuous deployment practices have allowed for significant shortening of development lead time, more frequent integration of code, and rapid placement of release candidates in a production environment.[34,35] More recently, practices such as DevOps, DataOps, and MLOps have been established as new ways of working within software-intensive embedded systems companies. These are practices that go beyond agile methods and that seek to further advance the automation and quality of production with regard to development, data, and ML operations.[36–38] Although these practices are still gaining momentum, they highlight the increasing importance of digital technologies and the ways in which these shape the capabilities of contemporary organizations. From a business perspective, data offer an important asset for new revenue. As we have recognized previously,[3] it can be used to subsidize the product side of the ecosystem by enabling new revenue streams, possibly with entirely new partners in new ecosystems. In addition, data are the fuel for AI/ML/DL models.[38,39] With massive data sets available, these models are trained to mimic human intelligence and allow companies to shift through massive data sets in order to stay on top of trends, provide answers to highly complex problems, and derive new insights. With software, data, and AI, companies are fundamentally changing their current processes and ways of working by automation of tasks in ways that were not possible before the era of digitalization. In this paper, we explore how digitalization transforms companies in the embedded systems domain. Based on empirical research, we present a model in which we detail the typical evolution path companies take when transitioning from traditional towards digital companies and we identify the open research challenges for future research.

3 | RESEARCH METHOD

3.1 | Case study research

The research reported in this paper is part of a larger research initiative in which we conduct longitudinal multicase study research[40,41] in close collaboration with 15 companies in the embedded systems domain.[1] The companies represent, for example, telecom, automotive, defense, security, healthcare, wind power, marine solutions, and logistics, and they are all large-scale software-intensive companies. With their products becoming increasingly connected, and with software, data, and AI being critical for innovation and new value creation, these companies are experiencing a rapid transformation of their businesses. Within this context, we have had the opportunity to work closely with the majority of the companies for more than 3 years on the topic of digitalization and digital transformation. In this particular paper, we report on our most recent work on how companies evolve from traditional to digital companies and we focus on identifying the typical evolution path and the steps necessary for realizing this. As a continuation of our previous work on digitalization in which we focused on the strategies that incumbents use to avoid disruption,[3] this study reports on our most recent work with three of the companies referred to as *primary* case companies. In these companies, we studied a total of five use cases in which the companies are complementing their traditional product offerings with new service-oriented offerings. In addition, and as *secondary* cases, we use insights and experiences from three additional companies that are experiencing similar challenges as the primary use cases in this study. As the basis for our findings, we use company workshops and qualitative interviews conducted between November 2018 and May 2020. In alignment with our research interests, we adopted a qualitative research approach.[41] As reported in literature,[41,42] case study research is especially well suited for research concerned with identifying patterns of action and for studying organizational contexts in which emphasis is put on stakeholder's perceptions, experiences, and understandings of a certain phenomenon.

3.2 | Data collection and analysis[2]

Our research builds on active engagement and close collaboration with practitioners in the case companies. As the basis for data collection, we organized workshops at each company, as well as joint workshops to which we invited all companies, we conducted interview studies, and we arranged meet-up events for product management, system engineers, system architects, and senior leaders within all companies. For data analysis, we adopted an interpretive approach.[41,43] As suggested by Walsham,[42] the generalizations that are made based on case study research are useful for other organizations that experience similar challenges in similar contexts.

3.3 | Case companies and use cases[3]

For the purpose of this publication, we selected a set of primary and secondary cases as the foundation for the conceptualizations and generalizations we present. As elaborated upon by Seawright and Gerring[44] and Gerring,[45] case study selection is critical as most case studies are about something larger than the case itself. In case studies of this sort, the chosen case is asked to represent a population of cases that is often much larger than the case itself, and typically, background cases play a key role in analysis. Following this line of reasoning, the empirical findings we report build on case study research in three companies that we selected as *primary cases*. As *secondary cases*, we selected another three case companies that face similar challenges and opportunities as the primary case companies. The three primary case companies are briefly described below:

- *Company A:* A company manufacturing trucks, buses, and construction equipment as well as a supplier of marine systems. For the purpose of this paper, we studied three different use cases that all reflect the transition towards a digital company. In Company A, we studied three different use cases, that is, *Case A1*, *Case A2*, and *Case A3*. These are detailed in Appendix A.
- *Company B:* A company manufacturing a broad variety of sports and utility vehicles. For the purpose of this paper, we studied a use case in which the company is looking to introduce on-demand pricing of products and services.
- *Company C:* A company developing products, services, and solutions for military defense and civil security. For the purpose of this paper, we studied a use case in which the company is exploring the opportunities to introduce digital products with continuous capability growth.

In addition to the primary cases, we studied three secondary case companies:

- *Company D:* A company developing a wide range of connected products for home appliances, for industry, and for transportation.
- *Company E:* A company providing information and communication technology (ICT) to service providers.

- *Company F:* A company providing processing and packaging solutions for food and beverages as well as services solutions for operation of manufacturing plants.

3.4 | Validity of results

As the foundation for our understanding of digital transformation, we reviewed contemporary studies on this topic. Based on this understanding, we conducted multicase study research in a set of selected primary and secondary case companies in the embedded systems domain. As our main data sources, we collected data from workshops and interviews with key stakeholders within each of these companies. To mitigate validity threats, and to address construct validity,[46] we started each workshop and each interview with sharing our definition of digitalization and what dimensions we regard critical for digital transformation. In this way, we created a common understanding for the key concepts, and we could focus the discussions using terminology that was familiar for everyone involved. With regard to external validity, we view our research contribution as related to the "drawing of specific implications" and as a contribution of "rich insights."[42] However, with the opportunity to study six companies covering different industry domains, and a total of eight separate use cases, we believe that the insights and the conceptual models we present have the potential to be relevant also in other embedded systems companies with similar characteristics as the six companies we studied. Although differences may exist with regard to the specifics of an individual company, there are reasons to believe that the overall evolution and the steps we identify are similar to what other embedded systems companies experience as they all originate in mechanics and electronics and with technologies such as software, data, and AI being added.

4 | EMPIRICAL FINDINGS[4]

In this paper, we explore how companies in the embedded systems domain experience the digital transformation of their businesses. In particular, we study a number of use cases in which these companies are complementing their traditional, and primarily transactional, models for value creation with models based on continuous value delivery to customers. This involves a shift from today's product sales to more service-oriented models for value creation. Below, we summarize the findings from the company workshops and interviews that provide the empirical foundation for this study. To structure the presentation of our empirical findings, we use the following dimensions: (1) product upgrade dimension, (2) business model dimension, (3) data exploitation dimension, and (4) AI/ML/DL dimension. These dimensions are empirically derived and were frequently referred to by workshop participants and interviewees when discussing the aspects of digital transformation.

4.1 | Company A: Automotive

Company A is a company manufacturing trucks, buses, and construction equipment as well as a supplier of marine systems. Currently, the software organization has adopted agile ways of working, but as the larger part of the organization consists of mechanics and electronics, the benefits of shorter development cycles have not yet been fully utilized. This is expressed by one of the senior engineering managers when saying: "We come from a waterfall background and now we are all agile, but we have not really changed …."

4.1.1 | Product upgrade dimension

Due to a strong tradition in mechanics, Company A describes fleet owners and customers as hesitant to digital solutions because so far, paper protocols have been what they trust and what they are used to. However, and as observed in *Case A1*, in order to provide drivers with real-time information before, during, and after a trip, Company A is planning to develop an integrated service that allows drivers to access services from a common platform. As a complement to the physical product, this will enable Company A to continuously update the software services provided on the platform as well as offer customers new business value in terms of real-time information. In addition, there will be an increased opportunity to prevent mistakes, accidents, and potential breakdowns before they happen. For Company A, the desire is to reduce cost and, at the same time, increase safety. Also, a common platform will help reduce the number of screens, apps, and phones that drivers use in order to access internal and external services. In this way, product complexity can be reduced, and drivers can minimize the number of physical items they use. In use *Cases A2* and *A3*, the "product" would consist of data that are shared and monetized with indirect and direct suppliers. From a product upgrade perspective, this allows fundamentally new value creation opportunities as the product would shift from a physical item to a digital offering.

4.1.2 | Business model dimension

In all three use cases, Company A is looking to explore new business models. In *Case A1*, Company A aims to introduce subscription-based services for fleet owners and customers in which access to data from external partners, as well as internal data revealing product performance, is intended to raise the total value of the service. This is in contrast to existing business models where Company A is the provider of the vehicles and related services but where direct access to data from external partners is limited. Also, there are currently no existing business models to which external partners contribute with value such as data. For Company A, success is when the new platform, and its connected services, is viewed as a transport "insurance" rather than a logistics app and when customers perceive the value of the services as "peace of mind" as they get continuously informed about vehicle conditions and trip environment.

Similarly, *Case A2* reflects a fundamentally new way of doing business as it involves sharing and monetizing data with suppliers. Up until now, Company A has been sharing certain types of data "for free" but without the opportunity to utilize the value of these data. To start monetizing data would allow a shift from today's product sales towards more of a service revenue model and with the additional opportunity to create a multisided ecosystem in which data generated from the primary customer base can be monetized with a secondary customer base. For example, data revealing road conditions and temperatures could be of potential interest to other stakeholders that are currently not customers of Company A. There are numerous challenges involved in this, including suddenly starting monetizing something that suppliers are used to get for free and that Company A does not know the value of. Ideally, Company A would want to have "a window" in which they can log the data, get the data, and analyze the data before sharing it with suppliers. This is not only due to the wish to understand the data before sharing it but also due to the fact that sharing data continuously might violate the competitive edge and the opportunity to still distinguish. As one company representative phrased it: "… it would be to just to give but without getting back." What is desired is to create a win–win situation with long-term benefits and a business model that allows for capturing parts of the value that suppliers generate based on the data.

In *Case A3*, a new business model would allow Company A to become a "stepping stone" in helping the supplier improve and develop new services. For doing this, there needs to be a model allowing for Company A to monetize the opportunity they provide.

4.1.3 | Data exploitation dimension

In all three use cases, data are a critical asset to either realize a new service or to be exploited and sold as a "product." As seen in *Case A1*, to have access to data that facilitate route planning, order matching, and tuning of onboard systems such as heating and cooling is critical. If offered in an integrated service, both time and costs associated with transporting of goods could be reduced. In addition, data facilitating loading, rest and delivery time, and station return of the vehicle would improve the overall efficiency of a trip. In *Case A2*, Company A is looking to exploit diagnostics and performance data. Although these data have been collected from the vehicles for decades, they have been used entirely for internal purposes and primarily for product maintenance. However, with products becoming increasingly connected, Company A is experiencing a situation in which more logs can be produced resulting in better and more accurate data from the products. Recently, this was recognized by one of the suppliers who wants access to the data coming back from their component as well as more of the diagnostics data produced by Company A. Finally, in *Case A3*, there is the situation of an indirect supplier that is willing to share data in order to also get data in return and where Company A could benefit from the supplier data to learn more about the specific component and overall product quality.

4.1.4 | AI/ML/DL dimension

All three use cases in Company A reflect systems in which large amounts of data are generated either from external sources such as sensors or from internal sources such as the electronic control units (ECUs). Currently, data from these different devices are used primarily for data analytics purposes and with the main intention to better understand product performance. Recently, Company A started to offer predictive maintenance services for which data are utilized as input for predicting when a certain error might occur. In relation to more advanced use of data, and with AI/ML/DL technologies involved, Company A is exploring the space of autonomous driving and already has the first autonomous solutions on the market. These vehicles are intended to increase efficiency and productivity in domains such as mining, underground operations where human safety is a concern, and in situations where there is a risk of accidents. As an example, Company A is currently involved in a project related to waste trucks that need to operate in housing areas. With a self-driving truck, only one operator is required, and the truck can operate largely automatically, which helps to increase both productivity and safety.

4.2 | Company B: Automotive

Company B is a company manufacturing a broad variety of sports and utility vehicles. The company operates within a large network of equipment manufacturers and suppliers and with close dependency to partners. Although the traditional suppliers represent hardware and mechanics, the digital transformation has brought with it a number of new partners in the areas of software, data, and AI with key competence in autonomous driving, virtual engineering, and continuous deployment. Currently, the automotive industry is experiencing rapid changes and disruptions due to new players utilizing digital technologies and offering fundamentally new business propositions. To manage this situation and to keep up with competition, Company B is required to rethink its current business as well as to invest in innovation. Also, and to avoid being disrupted by players like Tesla and Google, the company has to rethink its definition of value as the traditional notion of this has always been in terms of transportation. This is not how new entrants think about value. For these players, the data generated by the car and by the driver constitute value as an asset for new services and solutions that focus less on transportation and more on customer experience.

4.2.1 | Product upgrade dimension

Company B operates in a domain where the tradition has been to sell physical products "as is" and where product upgrades are few, if any. The regular maintenance and repair of the vehicle is the opportunity for improvement, but up until the last decade, software updates were not common. Recently, however, the company has started developing on-demand product areas where entire products, selected functions, and certain services are offered to customers in an on-demand fashion rather than sold "as is." The aim of this is to allow for frequent performance upgrades as well as continuous software and function upgrades. From a product upgrade perspective, this would shift focus from the selling point, that is, the transaction, of the product to the usage time of the product and it would enable software-driven and continuous updates of the system.

4.2.2 | Business model dimension

The traditional business model in Company A brings the highest proportion of revenue at the moment of purchase. Typically, the buying process and decision takes significant time because the product is both complex and costly. However, the time after purchase and when the product is actively used by customers is not utilized as an opportunity for monetization. In the use case we studied, Company B is introducing on-demand services as a means to reinvent their current business model. In the case of on-demand services, Company B develops services such as renting of particular items. For example, customers do not need to store extra equipment such as bike holders or roof racks but rather pay and get access only for the time period they need these items. Similarly, certain equipment could be made available for subscription so that customers would only pay the season they actually use them. The desired state is to have the current product sales complemented with significant product-as-a-service sales as well as complementary services around the physical product that allows for continuous revenue opportunities.

4.2.3 | Data exploitation dimension

With vehicles becoming increasingly connected, the development of connected services is exploding, and from having been a minor part of the business, it has become a differentiator. For example, services that alert drivers of road conditions and accidents as well as services that inform about maintenance are common. With such services, the use of data is shifting from being the primary input for troubleshooting to becoming an asset that can be monetized. If collected from one customer, data can be shared with this customer to help improve product performance as well as the overall driving experience. Furthermore, data provide insights that can be shared and monetized with existing customers as well as with new customer segments. For Company B, avoiding disruption is a challenging balance between focusing on the core value of providing customers with vehicles while reinventing itself by providing customers with new data-driven services that have less to do with the car but that add to the overall customer experience.

4.2.4 | AI/ML/DL dimension

Company B is actively pushing autonomous driving, and by the middle of the next decade, it is expected that a third of annual sales will be generated from autonomous cars. To realize a future of autonomous cars, Company B has established a number of new partnerships in the area of autonomous technology development, for example, partners developing the next generation of driver assistance software as well as software for autonomous cars. In addition, close partnerships have been established with smaller startups in order to develop advanced perception technology for use in autonomous cars. With these technology developments and partnerships, Company B is rapidly advancing their traditional data analytics practices to also include AI/ML/DL technologies and data stream-centric ways of working in which large data sets are used as the basis for dynamic training and retraining of models.

4.3 | Company C: Defense

Company C develops safety-critical systems for defense in a highly restricted domain. Today, the number of products in the product portfolio is high and the development and sales organizations are structured around these products. Overall, the company seeks to shorten time to market and shift development towards a digital product roadmap. In order to get there, Company C recognizes actions such as more frequent updates of feature roadmaps, an improved process for managing future feature development, a closer collaboration between product management and R&D (i.e., a DevOps setup), and the need for a roadmap based on insights from data and business intelligence rather than requirements.

4.3.1 | Product upgrade dimension

Currently, products are developed and sold using a traditional business model in which only sparse upgrades with minor capability growth take place. As the products are made to last for decades, and with as little interference as possible, interaction with customers is limited. Although the company offers a few services, the current business model is not tailored to support digital offerings or service-oriented revenue streams. However, with an increasing part of the products becoming software-intensive, and with rapid development of sophisticated AI/ML/DL technologies, Company C is looking to decrease the overall number of products and instead offer complementary services that allow for regular, or at least more frequent, product upgrades. Instead of many product variants, the company wants to offer customers a large variety of configurations and company representatives agree that software-driven improvement of functionality is critical for the near future.

4.3.2 | Business model dimension

In Company C, revenue is generated almost entirely out of traditional product sales. Some complementary services exist, but these are intended more as services supportive to the existing products rather than value-generating services by themselves. However, the company recognizes a number of new sales opportunities that open up with digitalization of products. During the workshops held at the company, it was clear that the ability to sell a set of continuously improving capabilities was considered key for future competitive advantage. One of the product owners defined digitalization as the ability to deliver continuous capability growth, the ability to sell add-on features to the current platform, and the ability to use data for continuous software improvement. According to this product owner, the challenges they face are partly related to the business domain in which they operate but also a result of a product-oriented business with transactions-based customer relationships. Another area of interest is to enable unbundling of existing offerings and a sales model that supports the sales of these as modules. Finally, to charge for competence is an opportunity, for example, maintenance competence, as continuous improvement of capabilities also includes continuous monitoring of errors and faults.

4.3.3 | Data exploitation dimension

With strict regulations and with access to customer data being limited, Company C has not had the opportunity to effectively utilize these data for revenue-generating insights or as an asset that could be monetized with customers. Although large data sets and advanced data analytics exist, these are used primarily for internal purposes and for product improvements rather than an additional business opportunity. However, Company C is experiencing an increased interest in the use of data—both internally as it could serve purposes in addition to quality assurance and diagnostics but also externally as customers are interested in using data to improve their own key performance indicators (KPIs). For Company C, the transition from quality assurance and diagnostics data towards data revealing feature usage is already a big step, but based on our interactions, we see a number of additional opportunities where Company C will benefit from a new revenue stream.

4.3.4 | AI/ML/DL dimension

Company C is currently exploring a range of opportunities related to AI/ML/DL technologies with examples such as a smart-technology digital cockpit for fighter jets, autonomous search and rescue drones, and smart sensors for land, air, and sea applications. As one example, AI technology is used to identify buildings, roads, or any type of land at pixel level from a great height, using AI segmentation to pick them out from the aerial shot. In addition, AI could be used in a fast-moving emergency where there is conflicting information and we need to establish what the current situation is, where, and how many casualties there are.

4.4 | Secondary case companies (Companies D, E, and F)

In addition to the three primary case companies, we have an ongoing collaboration with a number of additional embedded systems companies. As additional background and input for analysis and conceptual model development, we use insights from three of these companies as input for this study. All three secondary case companies operate in businesses where the product is a physical product, for example, a transportation device (Company D), a communication system (Company E), and a packaging plant (Company F). Just as the primary case companies, they are currently building complementary services around their products and they seek to advance the use and exploitation of the data that their products generate. With regard to AI/ML/DL, the companies have hundreds of people working with these technologies as they provide huge potential for new value propositions. Our research collaborations with these companies relate to all the dimensions presented in this paper and have been published in a number of studies in which we detail the cases, the challenges they face and the strategies they use to advance their products, their business models, their use of data, and their AI/ML/DL initiatives.[47–49]

5 | DISCUSSION: TOWARDS A DIGITAL COMPANY AND HOW TO GET THERE

In this paper, we explore how digitalization transforms companies in the embedded systems domain. To do this, we explore a number of use cases in which the case companies involved in our study seek to complement their traditional, and primarily transactional, models for value creation with models based on continuous value delivery to customers. In what follows, we discuss our empirical findings and we present the main contributions of this paper. First, in Section 5.1, we capture the difference between traditional and digital companies. Second, in Section 5.2, we present a model in which we detail the typical evolution path companies take when transitioning from traditional towards becoming digital companies. In this model, we identify four orthogonal dimensions in which companies need to evolve and that are critical for this transition to be successful and we outline the steps that need to be taken. In Section 5.3, we present the relation between our models and the empirical evidence from the cases. Finally, in Section 6, we identify open research challenges for future research.

5.1 | Traditional versus digital companies

During our research, one of the main discussions in the case companies was the definition of a "digital company" and what it actually means to become a digital company. During these discussions, together with the companies, we converged on a set of contrasts between traditional and digital companies. In Table 1, and based on the case company discussions, we provide an overview of the characteristics of traditional and digital companies and the contrast between the two.

TABLE 1 Contrasting traditional and digital companies: Key characteristics

Dimensions	Traditional company	Digital company
Business model	Transactional model where customers buy products periodically	Continuous value delivery model based on services; monetization through KPIs and expectation of continuous improvement
Business ecosystem	One-dimensional value network from suppliers to product company to customer	Multidimensional business network with multiple avenues for monetization using products, data, and other assets
Data	Customer has full ownership of its data and with limited (if any) access to it by the product company	The product company has ownership of customer data and uses it as an asset in product development and improvement and as an asset that is monetized with customers, for example, data-driven service offerings
System architecture	Deeply integrated architecture optimized for minimal bill of material cost. Focus is on freezing the architecture after design and a "big bang" release	Modularized architecture separating parts that evolve at different frequencies through APIs (mechanics, electronics, software). Focus is on facilitating continuous evolution and release
R&D process	Process dictated by mechanical design and manufacturing constraints. Focus on planning and prediction in order to minimize cost due to late changes and quality issues	Process focused on fast feedback loops facilitated by continuous deployment and data streams. Focus on experimentation and continuous learning
Organization	Hierarchical organization with functionally organized departments	Empowered, cross-functional teams responsible for different aspects of value delivery
Culture	Atoms-over-bits mindset and with a tendency for local optimization.	Bits-over-atoms mindset in which people deliver on the company mission and take on responsibilities based on what is needed

Abbreviation: KPI, key performance indicator.

5.2 | The evolution from a traditional to a digital company

In this section, we present the typical evolution path we see the case companies take when transitioning towards becoming digital companies. In Figure 1, we identify four orthogonal dimensions in which companies are evolving and that are critical for this transition to be successful. These dimensions are the (1) product upgrade dimension, (2) business model dimension, (3) data exploitation dimension, and (4) AI/ML/DL dimension. For each dimension, we outline five steps starting from traditional practices and product-oriented value creation to more service-oriented and data-driven revenue models. In the following subsections, we detail each of these dimensions and we identify the steps that we see companies take in order to become a digital company. From the primary and secondary case companies we worked with, we have empirical evidence for Steps 1–3 as those steps are where these companies currently operate. For Step 4, we have limited examples as this step is not fully realized in the embedded systems domain. However, all case companies direct their efforts and key initiatives on realizing this step, and with other domains (e.g., the online domain) already there, we expect the embedded systems companies to follow this path shortly. Finally, to develop a multisided market model[50–53] with additional opportunities to monetize data (Step 5) is based on what we learned is their desired state and where the case companies want to be although none of them are there yet. This step is where we see companies in the gaming and in the online domain operate, and it is reasonable to assume that the embedded systems companies will follow the same path. For each of the steps, we provide more detail in Section 5.3.

As an overall reflection with regard to the evolution path presented above, our experience is that the transactional business model is valid primarily for commodity and differentiating functionality.[54] With digitalization, however, this model is currently being complemented with subscription-based business models where customers pay a fee at regular intervals for access to a product or service. In the case companies we studied, we see that for more innovative services, the companies are looking to have a subscription- and service-based business model as this allows for more exploratory ways of working with customers. In addition, we see that companies look to have their suppliers align their business model with the main business model of the company as this allows for aligning the revenue model with the cost model. As one example, automotive producers want to avoid paying suppliers upfront if offering the car as a service but instead share part of the service revenue with suppliers. Finally, there is a difference with regard to B2B versus B2C with regard to ownership of certain products. In the automotive domain, there is an advantage with a business model focused on ownership, as then, the responsibility for the vehicle is with the owner and it is clear who pays for value-added services.

5.2.1 | Product upgrade dimension

In the companies we studied, there are already software updates to the products and associated services on a regular basis. In Figure 2, we detail the product upgrade dimension and we identify the steps that companies take when transitioning from selling physical products to selling digital products with continuous upgrades of all system components.

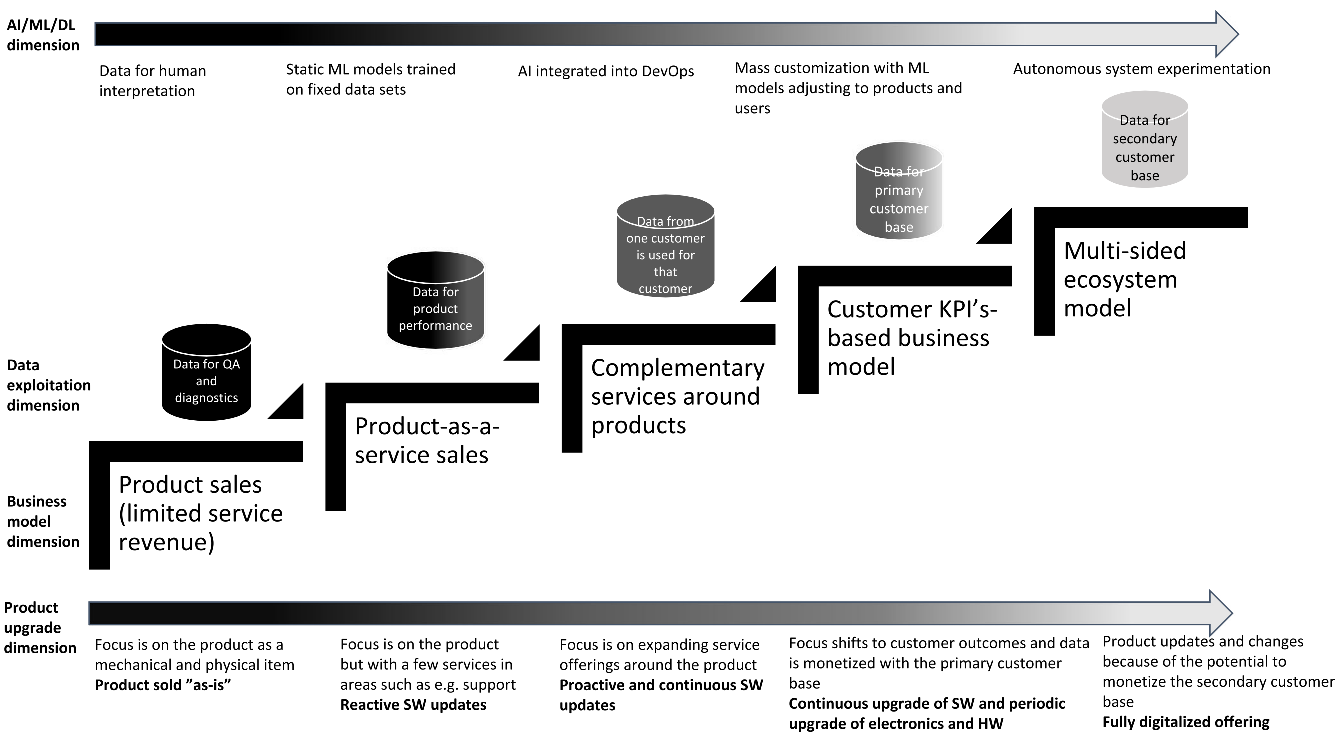

FIGURE 1 The evolution path from a traditional to a digital company
Abbreviations: AI, artificial intelligence; ML, machine learning; DL, deep learning; KPI, key performance indicator

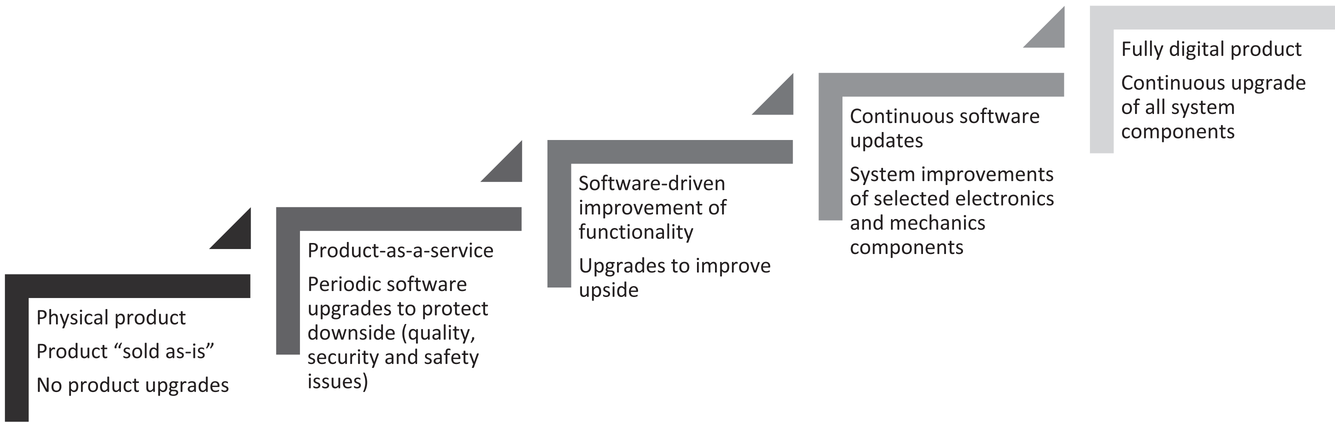

FIGURE 2 Evolution from a traditional to a digital company: The product upgrade dimension

As can be seen in the figure, there are intermediate steps where products are offered as a service, for example, car sharing services, and where software upgrades allow for improvement of system performance in terms of quality, security, and safety. In the second step, companies support software upgrades of products deployed in the field primarily to protect downside, for example, recalls due to quality or safety issues, and software updates are made to ensure and correct system behavior. In the next step, the data that are generated by customers when using the product and its complementary services are used for internal benefits, that is, improvement of product performance such as the detection capability of a radar system or to address issues with fuel consumption in certain road conditions. However, the further the companies evolve, the more upgrades to the product and services become connected to customer experience and the customers' business KPIs. In the last steps, the company starts to focus on upgrading selected electronic and mechanical parts with the goal of improving the business of the customer. In automotive, and especially in relation to trucks, we see this pattern when product companies move from being focused on the truck and its planned services towards focusing on upgrades that help fleet owners manage also the exceptional and unplanned situations and where software services help improve their business. In the final step, the product offering has digitalized completely, meaning that the company manages the physical product and its upgrades, and the customer enjoys a continuously improving solution.

5.2.2 | Business model dimension

All case companies seek to shift value delivery from today's transactional models towards more value-based models in which there is the opportunity for a more continuous relationship to customers and where the product is more of an enabler for selling complementary services and digital products that extend the lifetime of the product and improve it during use. In Figure 3, we detail the business model dimension and we identify the steps that companies take when transitioning from product sales to a multisided ecosystem.

In the first step, transactional sales of physical products are the primary source of revenue and anything services related is a secondary. At this step, customer interaction is limited as the product is seen as the primary value being delivered. In the second step, companies start providing a service in areas that were traditionally sold as products. In a product-as-service sales model, the producer typically gets a regular income stream as services may include subscription fees or use-based charges. As an example, customers joining a car sharing service have reduced upfront costs compared with buying a car but pay a regular fee that covers, for example, maintenance. In particular, customers that have insufficient need to warrant full ownership of the product benefit from a product-as-a-service model, and consequently, this model does, in most cases, complement, rather than cannibalize, the traditional business model. In the third step, companies expand on the service offerings and start building complementary services around their products. These services often concern guaranteeing certain properties of the product, such as availability, uptime, and mean time between failures. The typical model in this step, however, is guaranteeing a certain level of, for example, availability, and the company being penalized if its products fail to meet the agreed level. There is only a downside to the performance-based business model but no upside yet. As recognized by Shankar et al.,[55] complementary service offerings might include bundle offerings where collections of products and services can be completely independent but which add large value when combined (e.g., Microsoft products and their support services, a combination of products and services—a "best of breed" offering, multibenefit bundles where products and services are dependent on each other, and unrelated products and services that are brought together to offer larger value to customers). In the fourth step, companies shift towards using the KPIs of the customer as target outcomes. Here, KPIs reflect how well the product delivers on whatever it is that the customer prioritizes. Using the automotive domain as an

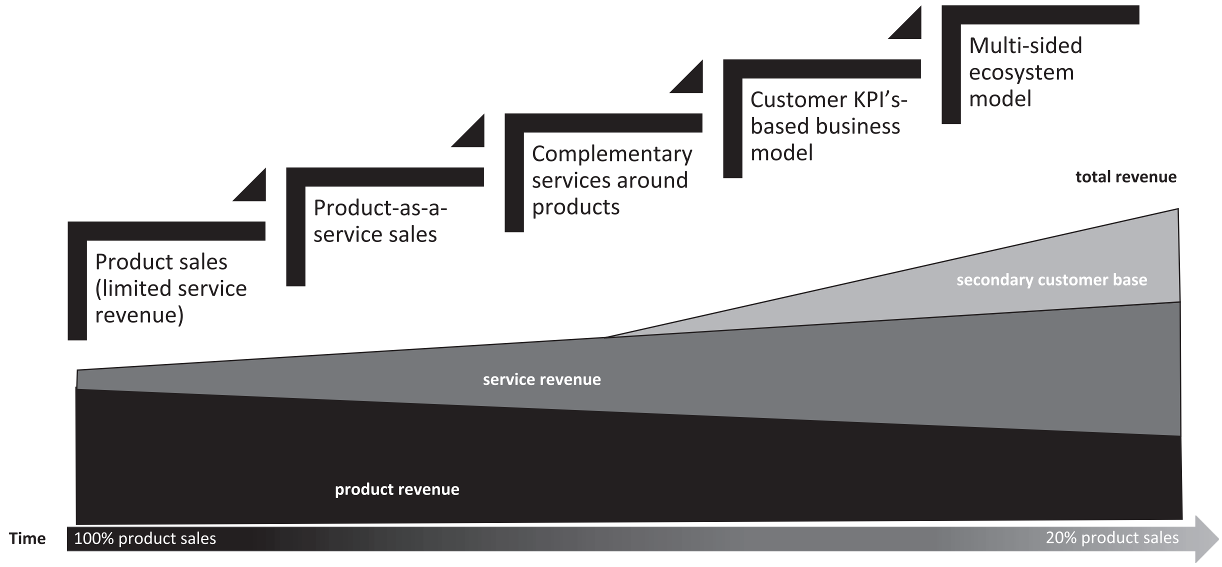

FIGURE 3 Evolution from a traditional to a digital company: The business model dimension

example, this can be, for example, how many of the scheduled transports delivered according to plan and without any delays. As another example, fleet owners in the automotive domain can get access to data about their fleet and with the opportunity to compare this with other fleets in order to see how they perform. Through aligning the business model with the customer KPIs, the company can now also benefit from providing improved performance (i.e., there is now an upside to the company to deliver more value). Finally, the fifth step reflects a multisided ecosystem model in which assets such as aggregated data coming from the primary customers are monetized with a secondary customer base. This forms the basis for a situation in which a company can subsidize the original customers by offering the product at a lower cost to gain market share.[50–53]

5.2.3 | Data exploitation dimension

In the companies we studied, we see enormous efforts in trying to improve the use and effectiveness of data. In Figure 4, we detail the data dimension of the digital transformation and we outline the steps companies take when moving from reactive use of data towards proactive use with the opportunity to monetize data with existing and new customers.

In the first step in the model, data are used as the basis for quality assurance and for diagnostics. Here, data help troubleshooting efforts as well as potential error-correcting activities and development teams benefit from having system behaviors continuously monitored. In the second step, companies start using data also for internal improvements of features, functionality, and product performance. As in the first step, data serve as input for troubleshooting and maintenance activities. In addition, however, the data are used for improvement of product performance, for example, the detection capability of a radar system or to address issues with fuel consumption in certain road conditions, configuration settings of a certain device, and other situations in which runtime data help improve the current version of the product. In the third step, companies advance further and start using data as an asset to monetize with existing customers. Here, data collected from one customer are processed and analyzed and provided back to the customer in order to support operations and provide relevant insights about the operations of that customer. In the fourth step, data from all customers are aggregated and used as an asset to provide, typically comparative, analysis and insights. In the automotive domain, data about a fleet are useful for the fleet owner if these can be compared with other fleets and how they are performing. In telecom, product companies use data to optimize their systems based on a certain operator's KPIs and they get internal benefits if they surpass these target outcomes. Finally, in Step 5, data from the original customer base are used to monetize with a second (and new) customer base. For example, data collected by vehicles could provide useful input for traffic conditions monitoring services and be monetized with customers outside the traditional customer base of an automotive manufacturer. It should be noted that companies are typically at multiple steps at the same time. As an example, companies that start using data for monetizing purposes (as defined in Steps 3–5) still use data for quality assurance and feature monitoring purposes (as defined in Steps 1 and 2). Similarly, a company that reaches the fifth and final step will still be using these data also as part of troubleshooting and maintenance activities. In this way, the data exploitation dimension pictures the way in which companies continuously extend the purposes for which data are utilized. As an overall

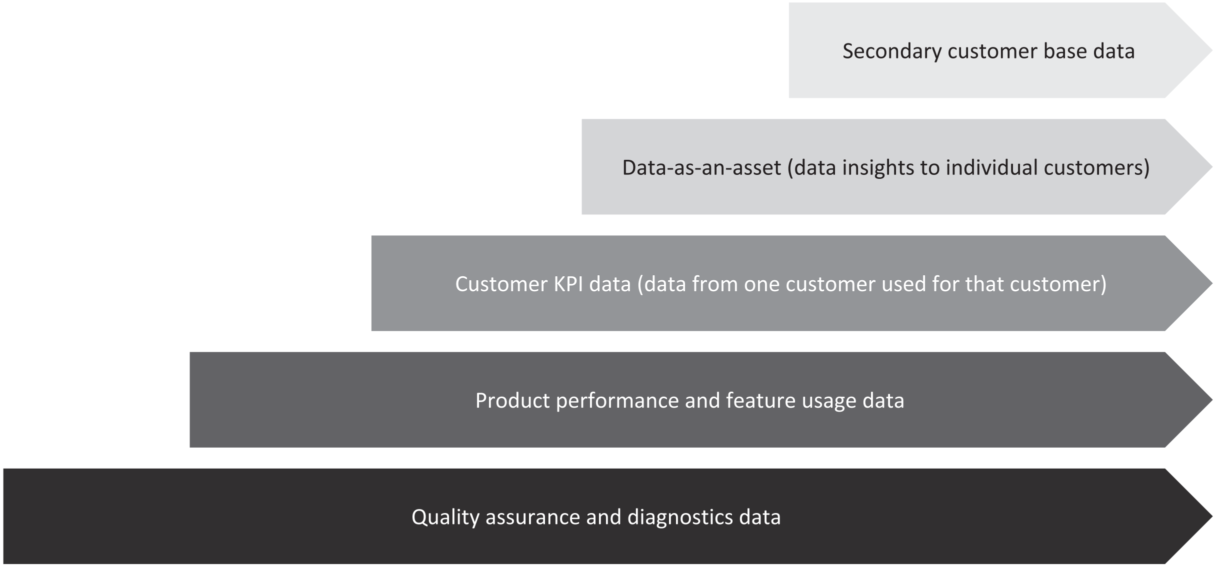

FIGURE 4 Evolution from a traditional to a digital company: The data exploitation dimension

reflection, all company representatives highlighted the desire to move from KPIs reflecting costs and price reduction towards metrics that emphasize customer value.

5.2.4 | AI/ML/DL dimension

All case companies have ongoing AI/ML/DL initiatives with hundreds of people working with these technologies. Despite the large range of topics and the questions each company seek to answer, typical areas include, for example, autonomous drive, fleet security, personalization of devices and/or offerings, nonverbal interaction, driving assistance, smart mobility, predictive maintenance, connectivity security, supply chain optimization, and speech and/or image recognition. At the moment, they all have their first deployments in operation, and they are exploring viable alternatives for how to effectively optimize and scale ML/DL model deployment. In Figure 5, we detail the AI/ML/DL dimension and we identify the steps that companies take when transitioning from simple data analytics practices to advanced and autonomous experimentation of AI/ML/DL models in operation.

As pictured in Figure 5, companies start with using data for analytics purposes with the intention to have AI technologies help them improve their software engineering processes. At this step, data are intended and used for human consumption and typical use cases are digitalization, optimization, and automation of processes. In the second step, companies adopt a data set-centric way of working in which they develop and train ML/DL models based on static data sets. At this stage, data become the primary and permanent asset on which applications are built, and each application reads and writes through the shared data model. As an example, one of the case companies uses ML models to check the packages they develop in order to detect any flaws or deviations in the sealings, in the gluing, or in the way the package is put together. Temperature, anomalies, and edges are analyzed to ensure quality of the sealings. Here, the data set consists of packages with different patterns and types. Following this, companies adopt more dynamic ways of working in which ML/DL models are continuously trained and retrained based on new data, new insights, and changing system behaviors. In one of the case companies, ML technologies are used to detect defects in packages at each customer site. A global and cloud-based ML model is deployed at each customer site to detect customer-specific defects using transfer learning. Learnings from each customer are sent back to the global model for retraining in the cloud. Here, the data set consists of fully finished packages with different patterns and types. In the fourth step, companies adopt federated learning approaches to further advance local training and enable localization and customization of models. As the case companies all develop embedded systems, the number of product instances is in the thousands and each instance has its own local deployment of ML/DL models. The case companies seek ways to complement central training with federated learning approaches where all product instances can be involved in continuously improving the performance of the entire product population in order to improve efficiency and reduce costs associated with central data storage. As learning takes place in deployed products, a key challenge is to balance traditional pre-deployment testing and quality and safety assurance practices with post-deployment evolution without sacrificing performance and safety of deployed systems. Finally, in the fifth step, companies have ML/DL models that explore and experiment autonomously to improve

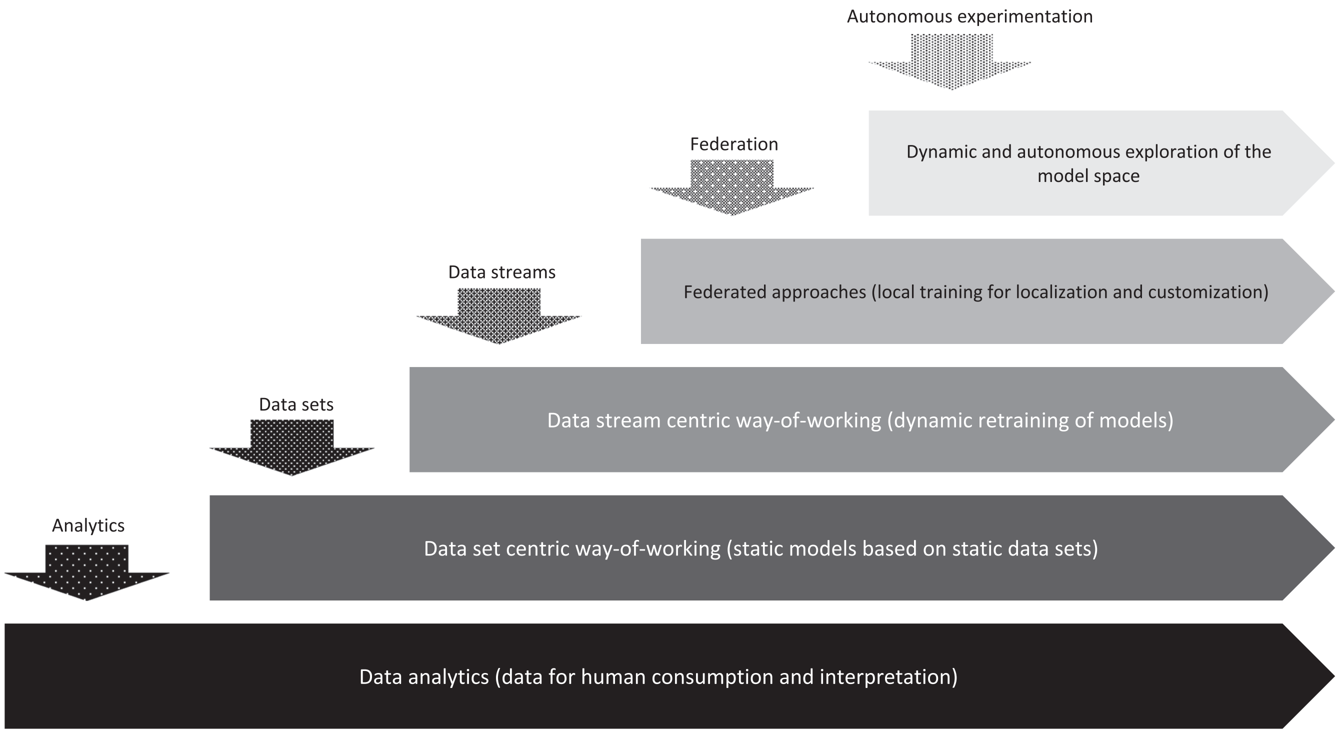

FIGURE 5 Evolution from a traditional to a digital company: The AI/ML/DL dimension

their performance. Here, the model experiments with different ways of realizing its functionality. As an example, systems like autonomous vehicles (including cars, trains, submarines, aircrafts, and ships) use advanced ML/DL technologies to learn from their own operation and improve quality of service. There are numerous research challenges surrounding this including the generation of alternatives for experimentation, the prediction of potential downsides (regret) of alternatives, and testing before deployment of experiments. Although we did not observe this step in the cases involved in our study, this was mentioned as a next step by several of the company representatives and as a desired evolution of their current practices.

5.3 | Summary: Empirical evidence for the conceptualizations

In the above sections, we presented a model in which we detail the typical evolution path that we see companies in the embedded systems domain take when transitioning from traditional to digital companies. Below, we present a mapping of the dimensions and steps we identified and the extent to which we observed these in the use cases we studied. In Table 2, we detail the notation we use when referring to the case companies and the extent to which the dimensions we describe were observable. As pictured in the table, we use four stars to denote the strongest form of confirmation, that is, where we have empirical evidence from multiple use cases, and one star for the weakest form of confirmation, that is, where a certain level of a dimension has been mentioned by at least one case company but where we have not yet seen this implemented in practice.

In Table 3, we use the above notation to present a mapping of the dimensions and steps we identified and the extent to which we observed these in the use cases.

As can be seen in the table, we were able to observe continuous practices in multiple case companies in relation to product upgrades and with several companies planning for fully digital products in the near future. With regard to business models, this dimension is challenging, and although multiple companies have complementary services around their products, we do not yet see effective models in which customer KPIs direct revenue and where the product company is able to significantly increase and grow service revenue. However, to increasingly monetize based on customer KPIs is something that is currently in development at several of the case companies. For example, this involves monetizing on the number of successful deliverables without delays if being a truck company, reaction time gained by earlier radar detection if being a defense company, or reduction of end-customer churn, which is critical for multiple cases. Similarly, although none of the case companies are able to monetize using a multisided ecosystem at this point in time, we regard this as a

TABLE 2 Notation used when describing our observations and interpretations in the case companies involved in the study

★★★★	**Observed in multiple use cases**
★★★	Observed in one use case
★★	Planned/wanted by multiple case companies
★	Mentioned/presented as an idea by at least one case company

TABLE 3 Mapping of empirical evidence for each of the steps that embedded systems companies take when evolving in the product upgrade, the business model, the data exploitation, and the AI/ML/DL dimensions of digital transformation

Dimension	Step 1	Step 2	Step 3	Step 4	Step 5
Product upgrade	Physical product	Product as a service	Software-driven improvement	Continuous software updates	Fully digital product
Empirical evidence	★★★★	★★★★	★★★★	★★★★	★★
Business model	Product sales	Product-as-a-service sales	Complementary services around products	Customer KPI-based business model	Multisided ecosystem
Empirical evidence	★★★★	★★★★	★★★★	★	★
Data exploitation	Quality assurance and diagnostics data	Product performance and feature usage data	Customer KPI data (data from a customer used for that customer)	Data as an asset (data insights to individual customers)	Secondary customer base data (data from primary customer base monetized with secondary customer base)
Empirical evidence	★★★★	★★★★	★★★★	★★	★
AI/ML/DL dimension	Data analytics	Data set-centric way of working	Data stream-centric way of working	Federated approaches	Dynamic and autonomous exploration of model space
Empirical evidence	★★★★	★★★★	★★★	★	★

Abbreviations: AI, artificial intelligence; ML, machine learning; DL, deep learning; KPI, key performance indicator

reasonable next step based on what is currently happening in other industry domains. As one example, and as recognized in Bataineh et al.,[56] data collected by smartphones are used in a variety of domains including targeted marketing, healthcare applications, pollution monitoring, and crime analysis, and companies like Google and Facebook earn a large part of their revenue by selling data of their users to other parties. Similar phenomena are reported in Voigt and Hinz[57] when exploring network effects in two-sided markets and how to mitigate negative effects between two user groups. Based on this trend, as well as on trends such as CI, CD, A/B testing, DevOps, and DataOps that have been successfully transferred from software companies to embedded systems companies,[34,35,58,59] it is reasonable to assume that companies in the embedded systems domain will also exploit and benefit from the opportunity to monetize customer data outside existing customer segments. Data exploitation practices are rapidly advancing, and here, we observed the increasing use of data for the benefit of customers. Based on the current state in the case companies, we foresee a future in which they are able to monetize not only their primary customer base but also secondary customer segments based on the data they collect. Finally, the extent to which AI/ML/DL technologies provide new business opportunities is phenomenal. Our study shows that the case companies are rapidly adopting these technologies and that these will be critical for competitive advantage as well as for the success of the digital transition they are experiencing.

6 | OPEN RESEARCH CHALLENGES

In this paper, we explore how digitalization transforms companies in the embedded systems domain, and we detail the typical evolution path these companies take when transitioning from traditional towards becoming digital companies. Below, we present key areas in which we identify open research challenges that need to be addressed in future research and in order to help companies further advance this transformation.

6.1 | Business model

Although business models and how to innovate these have been extensively studied,[1,4,7,60] the specifics of the embedded systems domain make this a complex area with a number of challenges to consider in future research.

6.1.1 | From product to service sales

The transition from a product-based sales model in which "free" service offerings are included as part of product sales to a stand-alone commercial services model is critical but not extensively studied.

6.1.2 | From cost to value-based models

For embedded systems companies, the issue of how to avoid getting stuck in business models that focus on costs rather than opportunities such as value-based pricing is critical. Although there is significant research on value-based pricing, there is little research on the transition from cost to value.

6.1.3 | Value capture from suppliers

Most product companies are uncertain as to how to capture value from data shared with suppliers. The challenge is that both parties want to receive any data for free but want to monetize the data when sharing. Research is required to develop conceptual models to support the negotiation between suppliers and product companies.

6.2 | Business ecosystem

The business ecosystem in which a company operates is of critical importance. As recognized in our previous research,[8] the strategies for how to engage with partners, competitors, and potential new entrants are critical for success. Also, the ways in which companies position themselves and how they shift and increase power are a key competitive advantage. Still, there are a number of challenges to consider.

6.2.1 | Partnering with or isolating new entrants

For embedded systems companies that develop products including mechanics, electronics, and to an increasing extent also software, data, and AI, there is an intricate balance between the risk of becoming a commodity player due to missing fundamental shifts in the market and wasting resources on, in hindsight, irrelevant innovations. One of the key factors in this balance is the decision concerning who to partner with. Here, we see two strategies: either keystone firms partner with new entrants with the intent to disrupt existing competitors, or they partner with their current competitors to keep new entrants out. There is little research supporting the strategic choices companies take concerning business and software ecosystems.

6.2.2 | Timing of transition between traditional and digital ways of working

In our research, we present four dimensions in which companies need to evolve and shift current practices. To survive and be successful, companies need to shift in all of these, but when to do what is challenging. The fact that new ways of working and new models have to grow whereas the old ways of working and models have to decrease has proven difficult as it includes not only development but also resources, competences, customer relations, supplier relationships, and so forth.

6.2.3 | Development of a two-sided business

To explore who is interested in certain data to the point that they are willing to pay for it is a challenging task for embedded systems companies. Also, the notion of how to put enough resources, attention, and funds into the development of a two-sided market in order to reach an ignition point where there is enough value created on both sides of the market is unclear.

6.3 | Data

Strategies for how to effectively manage and monetize data are key for companies that seek to provide services and continuous software updates to customers.[3,12,13] This topic comes with a set of challenges specifically for embedded systems companies:

6.3.1 | Data ownership and changing ownership

Embedded systems companies have traditionally focused on selling physical products and claimed that the customers own the data generated by their products. This is rapidly changing. Consequently, there is the challenge of how to share data with multiple stakeholders.

6.3.2 | How to value and price data

As data have not been monetized in existing supplier relationships, nobody knows what the value (the price) of these data is and there is uncertainty of what the potential use scenarios of these data could be when in the hands of suppliers. In addition, there are no common guidelines on how to associate value with data sets and data streams or how to distinguish between direct and indirect factors such as risk and warranty.

6.4 | System architecture

As embedded systems include mechanical, electronic, and software parts, defining a system architecture that supports the seamless integration of these parts is of critical importance. Traditionally, all parts were designed in parallel, integrated, validated, and frozen as a transactional business model is based on infrequent, large system upgrades that justify the next transaction. When digitalizing, embedded systems companies need to adopt more continuous value delivery to customers.[3] This leads to a number of interesting research challenges.

6.4.1 | How to architecture the traditional product in layers that can evolve independently of each other

As software, electronics, and some mechanical parts now all need to evolve at different frequencies, we need to decouple layers in the system architecture that facilitate the different update frequencies without losing overall system functionality. This is a surprisingly challenging topic as each of the technologies brings requirements and constraints to the system architecture.

6.4.2 | How to manage the increasing system scope

Traditional system architecture focused on the physical product, but in a digital context, the system architecture has to include the cloud backend, mobile apps, and third parties that integrate with the core system.

6.5 | R&D process

Embedded systems companies have rigorous processes that dictate how to work with a complex set of components as well as how to efficiently integrate these. Typically, systems are safety-critical, which adds a dimension to the level of complexity as well as to the adoption capability of new ways of working. During recent years, agile methods and DevOps practices have been implemented.[36] With digitalization, however, there are a number of additional challenges to consider.

6.5.1 | Sequential versus continuous ways of working

For embedded systems companies, the tradition is to focus on waterfall development of products as this is a well-working and common approach to mechanics and electronics components of the systems. The challenge is to have waterfall and sequential approaches for mechanics and electronics co-exist with agile and continuous deployment of software, data, and AI.

6.5.2 | Development of service offerings and new capabilities

R&D as well as sales organizations need to adopt service-oriented methods and ways of working that shift focus to emerging service offers and new capabilities, for example, cloud service delivery.

6.6 | Organization and culture

Typically, embedded systems companies are organized in hierarchical company structures with roles and responsibilities that reflect the product portfolio. With increasingly service-oriented businesses, this needs to change. Although cross-functional teams and the transition towards these have been studied,[61] this is particularly challenging in large-scale software engineering.

6.6.1 | From hierarchical to cross-functional organizations

With digitalization, companies need to re-organize themselves. For embedded systems companies, this involves the transition from hierarchical organizations with separate functions and departments towards empowered and cross-functional teams focused on delivering end-to-end services including the product, cloud backend, mobile apps, and third-party integration.

6.6.2 | From an "atoms over bits" to a "bits over atoms" mindset

To advance as digital companies, embedded systems companies need to change the organization and the mindset of people into something in which people deliver on the overall company mission and where employees take on responsibilities based on what is needed rather than what is stated in a role description.

7 | RELATED WORK

The phenomenon of digitalization is widely studied across research disciplines. As examples, there are studies on how business models typically shift and change over time,[62] on the emergence of multibusiness models,[63] and on how companies are able to create two-sided markets where distinct user groups provide each other with network benefits.[50–53] Examples of well-known companies employing two-sided markets include organizations such as American Express (credit cards), eBay (marketplace), Taobao (marketplace in China), Facebook (social medium), LinkedIn (professional medium), Mall of America (shopping mall), Match.com (dating platform), and Sony (game consoles). As recognized in Bataineh et al.,[56] the benefits that each group exhibits demand economies of scale. Credit card holders, for instance, favor credit cards accepted by more merchants, whereas merchants favor cards carried by more holders. Two-sided market platforms choose the right price to charge each group and consider the fact that adoption on one side drives adoption on the other side. In similar, data collected from one customer group can be monetized with another customer group in order for companies to gain market share and accelerate revenue provided by customer data. In addition, several authors discuss the dynamic nature of business models and the impact of change in the business environment.[63–65] Complementing these studies, there are studies on how digitalization drives organizational change at the process, organization, and business level. Although these studies are not directed towards the embedded systems industry, they provide insights in how digitalization offers significantly shorter transaction times and how an increased speed drives new challenges in business and technology alignment. Regardless of research discipline or perspective taken on digitalization, one of the most fascinating trends is the shift towards continuous value delivery to customers and continuous improvement and deployment of product functionality. This shift is observed across industry domains and to an extent that we have only seen the beginnings of.[25,26]

Despite rigorous research on digitalization, there is limited research within the software engineering field that focus on what it involves for embedded systems companies to transform into digital companies. Typically, there is a strong tendency to focus on either the enabling technologies for digitalization, for example, continuous integration and continuous deployment[34,35] or the practices associated with these.[36–38] As recognized by Ståhl et al.,[34] the successful implementation and use of these technologies and practices allow for significant shortening of development lead time, more frequent integration of code, and rapid placement of release candidates in production. As a result, new value is created and there is the additional opportunity for new monetization strategies. Related to studies on technologies and practices, our previous work recognized how embedded systems companies use different strategies for collaborating and competing within the business ecosystems they operate in,[8] how they position and reposition themselves in these ecosystems,[14] and how digitalization and the introduction of new technologies disrupt current development practices and forces incumbents to use new strategies.[3]

However, although there are studies within software engineering that focus on topics related to digital transformation, these studies tend to adopt more of a technical or a practice perspective of digitalization. To the best of our knowledge, the business aspects of digitalization are primarily studied outside of the software engineering research field. For the software engineering field of research, this means that there is a tendency to neglect the monetization part of new technology-driven opportunities rather than bringing these together into a holistic understanding of what digitalization entails. Although we believe that existing software engineering research provides a solid foundation for some of the dimensions of digitalization, it fails in detailing what it takes to transition from a traditional company with value being created from product sales towards becoming a digital company with complementary digital and service-oriented offerings. Moreover, existing studies do not provide insights into the implications of a continuous customer relationship in which the lifetime of a product is significantly extended and in which customer value is created throughout the lifetime of a product.

Therefore, and to complement our own previous research as well as previous research by others, this study focuses exclusively on the software-intensive embedded systems domain and the specific needs of these companies to successfully navigate the digital transformation. In our previous work, we focused on how customer needs evolve when new technologies are introduced, how ecosystems transform due to digital technologies, and how traditional technologies commoditize over time. Based on our findings, we developed a decision framework that captures technical aspects of digitalization as well as alternative strategies that incumbents can use to avoid disruption. However, we did not focus our attention on the value creation and business model aspects of digitalization. Therefore, in this paper, we conceptualize this transformation, and we identify the steps that embedded systems companies need to take to become digital companies. As the key contributions, our study captures the difference between what constitutes a traditional and a digital company and we detail the typical evolution path companies take when transitioning from traditional towards becoming digital companies. In doing this, we aim to provide a holistic understanding of the different dimensions of digitalization and how embedded systems companies need to evolve in each of these to successfully transform into a digital company.

8 | CONCLUSIONS

With digitalization and with technologies such as software, data, and AI being introduced, companies in the embedded systems domain are experiencing a rapid transformation of their conventional businesses. While the physical products and associated product sales provide the core revenue, these are increasingly being complemented with service offerings, new data-driven services, and even pure digital products that allow for continuous value creation and delivery to customers. For the companies studied in this paper, the transition from being traditional companies towards becoming digital companies offers the opportunity to significantly expand their business and to engage with customers in new and innovative ways. However, and as recognized in this paper, although the embedded systems domain has been carefully studied with regard to its transition from products to services and how digitalization and new technologies disrupt current development practices,[3,8,34–36] there is limited research on what it involves to transition from a traditional company with value being created from product sales towards becoming a digital company with complementary digital and service-oriented offerings.

In this paper, and based on multicase research, we explore a number of use cases in the embedded systems domain in which companies seek to complement their traditional, and primarily transactional, models for value creation with models based on continuous value delivery to customers. As our key contributions, we (1) capture the difference between traditional and digital companies, we (2) present a model identifying four orthogonal dimensions in which companies need to evolve when transitioning from traditional towards digital companies, and (3) we identify open research challenges that we see as important for future research in this area. In future work, we aim to study several of the open research challenges in more detail, especially those concerning the business ecosystem, data, and R&D processes. In addition, we hope to validate the model with additional companies. Transitioning from a traditional to a digital company is the key contemporary challenge in the embedded systems industry and we intend to provide helpful conceptual models and empirical evidence to support existing keystone players in surviving and thriving in the digital transformation.

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ENDNOTES

[1] For more information about this research collaboration, please visit www.software-center.se

[2] A detailed description of our data collection and analysis activities can be found in Appendix A.

[3] A detailed description of the use cases in each company can be found in Appendix A.

[4] An overview of the interview and workshop guidelines/questions can be found in Appendix B.

REFERENCES

1. Lefaix-Durand A, Kozak R. Integrating transactional and relational exchange into the study of exchange orientation in customer relationships. *J Mark Manag*. 2009;25(9–10):1003-1025.
2. https://marksanborn.com/blog/2013/02/25/9-differences-between-transactional-and-relational-how-to-tell-the-difference
3. Olsson HH, Bosch J. Going digital: disruption and transformation in software-intensive embedded systems ecosystems. *Journal of Software: Evolution and Process*. 2020;e2249. https://onlinelibrary.wiley.com/doi/abs/10.1002/smr.2249
4. Payne A, Holt S. Diagnosing customer value: integrating the value process and relationship marketing. *Br J Manag*. 2001;12(2):159-182.
5. Bosch J, Olsson HH. Toward evidence-based organizations: lessons from embedded systems, online games, and the Internet of Things. *IEEE Softw*. 2017;34(5):60-66.
6. Figalist I, Elsner C, Bosch J, Olsson HH. Business as unusual: a model for continuous real-time business insights based on low level metrics. In Proceedings of the 45th Euromicro Conference on Software Engineering and Advanced Applications (SEAA). 2019:66–73.
7. Teece DJ. Business models, business strategy and innovation. *Long Range Plan*. 2010;43(2–3):172-194.
8. Olsson HH, Bosch J. From ad-hoc towards strategic ecosystem management: the three-layer ecosystem strategy model. *Journal of Software: Evolution and Process*. 2017;29(7):e1876.
9. Olsson HH, Bosch J. Collaborative innovation: a model for selecting the optimal ecosystem innovation strategy. In: Proceedings of the 42nd Euromicro Conference on Software Engineering and Advanced Applications (SEAA), August 31 – September 2, Limassol, Cyprus. 2016:392–399.

10. Manikas K, Hansen KM. Software ecosystems: a systematic literature review. *J Syst Softw*. 2013;86(5):1294-1306.
11. Bosch J. Speed, data and ecosystems: future trends in software engineering. *IEEE Softw*. 2016;33(1):82-88.
12. Loebbecke C, Picot A. Reflections on societal and business model transformation arising from digitization and big data analytics: a research agenda. *J Strateg Inf Syst*. 2015;24(3):149-157.
13. Matt C, Hess T, Benlian A. Digital transformation strategies. *Bus Inf Syst Eng*. 2015;57(5):339-343.
14. Bosch J, Olsson HH. Ecosystem traps and where to find them. *Journal of Software: Evolution and Process*. 2018;30(11):e1961. https://onlinelibrary.wiley.com/doi/abs/10.1002/smr.1961
15. Selander L, Henfridsson O, Svahn F. Capability search and redeem across digital ecosystems. *J Inf Technol*. 2013;28(3):183-197.
16. Berman S, Marshall A. The next digital transformation: from an individual-centered to an everyone-to-everyone economy. *Strateg Leadersh*. 2014;9-17.
17. Luna-Reyes LF, Gil-Garcia JR. Digital government transformation and internet portals: the co-evolution of technology, organizations, and institutions. *Gov Inf Q*. 2014;31(4):545-555.
18. Sahu N, Deng H, Mollah A. Investigating the critical success factors of digital transformation for improving customer experience. In International Conference on Information Resources Management (CONF-IRM). Association for Information Systems. 2018.
19. Henfridsson O, Nandhakumar J, Scarbrough H, Panourgias N. Recombination in the open-ended value landscape of digital innovation. *Inf Organ*. 2018;28(2):89-100.
20. Svahn F, Mathiassen L, Lindgren R. Embracing digital innovation in incumbent firms: how Volvo cars managed competing concerns. *MIS Q*. 2017;41(1):239-253.
21. Schuchmann D, Seufert S. Corporate learning in times of digital transformation: a conceptual framework and service portfolio for the learning function in banking organisations. *International Journal of Advanced Corporate Learning (iJAC)*. 2015;8(1):31-39.
22. Benbya H, Nan N, Tanriverdi H, Yoo Y. Complexity and information systems research in the emerging digital world. *MIS Q*. 2020;44(1):1-17.
23. Chesbrough H. Business model innovation: opportunities and barriers. *Long Range Plan*. 2010;43(2–3):354-363.
24. Gambardella A, McGahan AM. Business-model innovation: general purpose technologies and their implications for industry structure. *Long Range Plan*. 2010;43(2–3):262-271.
25. Baden-Fuller C, Mangematin V. *Business models and modelling*. Bingley, England: Emerald Group Publishing; 2015.
26. Casadesus-Masanell R, Ricart JE. Competitiveness: business model reconfiguration for innovation and internationalization. *Management Research: Journal of the Iberoamerican Academy of Management*. 2010;123-149.
27. https://www.i-scoop.eu/digital-transformation/digitization-digitalization-digital-transformation-disruption
28. Bowersox DJ, Closs DJ, Drayer RW. The digital transformation: technology and beyond. *Supply Chain Management Review*. 2005;9(1):22-29. https://search. proquest.com/docview/221201326?accountid=15518
29. Mazzone DM. *Digital or death: digital transformation: the only choice for business to survive smash and conquer*. Mississauga, Canada: Smashbox Consulting Inc.; 2014.
30. Schallmo D, Williams CA, Boardman L. Digital transformation of business models—best practice, enablers, and roadmap. *Int J Innov Manag*. 2017;21(08):1740014.
31. Berman SJ. Digital transformation: opportunities to create new business models. *Strateg Leadersh*. 2012;16-24.
32. Bharadwaj A, El Sawy OA, Pavlou PA, Venkatraman N. Digital business strategy: toward a next generation of insights. *MIS Q*. 2013;37(2):471-482.
33. Kreutzer RT. Digital darwinism and the need for a digital transformation. In International Conference on Business Strategy and Organizational Behaviour (BizStrategy). Proceedings. Global Science and Technology Forum. 2014:38.
34. Ståhl D, Martensson T, Bosch J. Continuous practices and devops: beyond the buzz, what does it all mean?. In 2017 43rd Euromicro Conference on Software Engineering and Advanced Applications (SEAA). IEEE. 2017:440–448.
35. Mårtensson T, Ståhl D, Bosch, J. Continuous integration applied to software-intensive embedded systems—problems and experiences. In: International Conference on Product-Focused Software Process Improvement. Springer, Cham. 2016:448–457.
36. Lwakatare LE, Karvonen T, Sauvola T, Kuvaja P, Olsson HH, Bosch J, Oivo M. Towards DevOps in the embedded systems domain: why is it so hard? In: 2016 49th Hawaii International Conference on System Sciences (HICSS). IEEE. 2016:5437–5446.
37. Atwal H. DevOps for DataOps. In: *Practical DataOps*. Berkeley, CA: Apress; 2020:161-189.
38. MLOps: https://whatis.techtarget.com/definition/machine-learning-operations-MLOps
39. Amershi S, Begel A, Bird C, De Line R, Gall H, Kamar E, Nagappan N, Nushi B, Zimmermann T. Software engineering for machine learning: a case study. In 2019 IEEE/ACM 41st International Conference on Software Engineering: Software Engineering in Practice (ICSE-SEIP). IEEE. 2019:291–300.
40. Easterbrook S, Singer J, Storey M-A, Damian D. Selecting empirical methods for software engineering research. In: Shull F, Singer J, Sjøberg DIK, eds. *Guide to Advanced Empirical Software Engineering, 2008*. London: Springer; 2008.
41. Maxwell JA. *Qualitative Research Design: An Interactive Approach*. 2nd ed. Thousands Oaks, CA: SAGE Publications; 2005.
42. Walsham G. Interpretive case studies in IS research: nature and method. *Eur J Inf Syst*. 1995;4(2):74-81.
43. Maguire M, Delahunt B. Doing a thematic analysis: a practical, step-by-step guide for learning and teaching scholars. *All Ireland Journal of Higher Education*. 2017;9(3):3351.
44. Seawright J, Gerring J. Case selection techniques in case study research: a menu of qualitative and quantitative options. *Polit Res Q*. 2008;61(2):294-308.
45. Gerring J. What is a case study and what is it good for? *Am Polit Sci Rev*. 2004;98(2):341-354.
46. Maxwell JA. Understanding and validity in qualitative research. *Harv Educ Rev*. 1992;62(3):279-301.
47. Lwakatare L, Raj A, Bosch J, Olsson HH, Crnkovic I. A taxonomy of software engineering challenges for machine learning systems: an empirical investigation. International Conference on Agile Software Development, Springer, Cham. 2019:227–243.
48. Olsson HH, Bosch J. Data driven development: challenges in online, embedded and on-premise software. In: International Conference on Product-Focused Software Process Improvement, Springer, Cham. 2019:515–527.
49. Fabijan A, Dimitriev P, Olsson HH, Bosch J. The evolution of continuous experimentation in software product development: from data to a data-driven organization at scale. In: Proceedings of the 39th International Conference on Software Engineering (ICSE). 2017:770–780.
50. Rochet JC, Tirole J. Platform competition in two-sided markets. *J Eur Econ Assoc*. 2003;1(4):990-1029.

51. Rochet JC, Tirole J. Two-sided markets: a progress report. *Rand J Econ*. 2006;37(3):645-667.
52. Eisenmann T, Parker G, Van Alstyne MW. Strategies for two-sided markets. *Harv Bus Rev*. 2006;84(10):92-101.
53. Armstrong M, Wright J. Two-sided markets, competitive bottlenecks and exclusive contracts. *Economic Theory*. 2007;32(2):353-380.
54. Bosch J. Achieving simplicity with the three-layer product model. *Computer*. 2013;46(11):34-39. https://doi.org/10.1109/MC.2013.295
55. Shankar V, Berry LL, Dotzel T. A practical guide to combining products and services. *Harv Bus Rev*. 2009;7. https://www.thecasecentre.org/corporate/products/view?id=91758
56. Bataineh AS, Mizouni R, El Barachi M, Bentahar J. Monetizing personal data: a two-sided market approach. In: ANT/SEIT. 2016:472–479.
57. Voigt S, Hinz O. Network effects in two-sided markets: why a 50/50 user split is not necessarily revenue optimal. *Bus Res*. 2015;8(1):139-170. https://doi.org/10.1007/s40685-015-0018-z
58. Munappy AR, Mattos DI, Bosch J, Olsson HH, Dakkak A. From ad-hoc data analytics to DataOps. In: Proceedings of the International Conference on Software and System Processes. 2020:165–174.
59. Mattos DI, Dakkak A, Bosch J, Olsson HH. Experimentation for business-to-business mission-critical systems: a case study. In: Proceedings of the International Conference on Software and System Processes. 2020:95–104.
60. Fjeldstad OD, Snow CC. Business models and organization design. *Long Range Plan*. 2018;51(1):32-39.
61. Dingsøyr T, Moe NB. Towards principles of large-scale agile development. In: International Conference on Agile Software Development, Springer, Cham. 2014:1–8.
62. Zott C, Amit R. Business model design: an activity system perspective. *Long Range Plan*. 2010;43(2–3):216-226.
63. Snihur Y, Tarzijan J. Managing complexity in a multi-business-model organization. *Long Range Plan*. 2017;51(1):50-63.
64. Cosenz F, Noto G. A dynamic business modelling approach to design and experiment new business venture strategies. *Long Range Plan*. 2018;51(1):127-140.
65. Doz YL, Kosonen M. Embedding strategic agility: a leadership agenda for accelerating business model renewal. *Long Range Plan*. 2010;43(2–3):370-382.

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APPENDIX A.

In the sections below, we provide a detailed description of the *data collection and analysis process* and *the case companies and the use cases*. These descriptions extend and detail Sections 3.2 and 3.3 in the paper.

Data collection and analysis

Our research builds on active engagement and close collaboration with practitioners in all the case companies. All research projects are organized in 6-month sprints during which we collect empirical data by exploring and identifying challenges related to a certain topic, develop solutions, validate results, and report these results. As the basis for data collection, we organize company-specific workshops at each company, as well as joint workshops to which we invite all companies, we conduct interview studies, and we arrange community meet-up events for product management, system engineers, system architects, and senior leaders within all member companies.

As the primary data source for this study, we engaged in *company-specific workshop* sessions at all case companies in which key stakeholders shared their experience on how the companies seek to complement their traditional, and primarily transactional, models for value creation with models based on continuous value delivery to customers. For the companies involved in this study, this involves the creation and monetization of new digital services as well as the transition towards a multidimensional value network in which revenue is generated from multiple avenues including products and services but increasingly from data and other digital assets. During these workshops, we met with groups of company representatives to learn about their ongoing initiatives on digital business models and new revenue streams as well as plans and ideas for future innovation of their product offerings. Typically, the workshop sessions lasted for 2–3 h and involved 4–10 people within product management, project management, business intelligence, innovative purchasing, advanced engineering, software applications, global software engineering, service business, and also people from feature and functionality development. In some cases, we had sessions that were half- or full-day events and in which we were invited to explore a specific challenge together with a team and where the team felt that they would benefit from having external input on their ongoing and future plans. In addition to the company-specific workshops, we organized *joint workshops* to which all companies were invited and where we together explored a selected topic related to digitalization and digital transformation. At these workshops, we typically had 12–20 people attending and with the added benefit of having the company representatives share experiences and learn from others. In total, we met with the involved case companies (including both primary and secondary case companies) in 27 workshops of which 16 workshops were on-site company-specific sessions where we visited each case company and met with representatives from that company, eight were joint workshops to which all companies were invited (including sprint kick-off workshops as well as sprint reporting workshops), one was a *community workshop* especially for product managers, and two were *community workshops* especially for senior leaders. Of the 16 company-specific workshops, 10 were conducted with teams at the primary case companies and six at the secondary case companies.

In addition to the workshops that were conducted between November 2018 and May 2020, and as complementary data sources, five semi-structured interviews were held with selected key stakeholders in two of the primary case companies and two of the secondary case companies. These interviews were conducted in November 2018 (two interviews), in October 2019 (one interview), and in April 2020 (two interviews). The interviews lasted for 45–60 min with the purpose to complement and further detail some of the aspects that emerged during the workshop sessions. All interviews were either recorded or documented in notes and the transcripts were shared between the two authors of this paper. Also, the empirical material and our interpretations of this were shared with the case company representatives on a continuous basis in order to avoid any misunderstandings as well as to get their feedback on the generalizations and conceptualizations we developed as part of our research. A summary of our data collection activities is presented in Table A1 where we use a "*" to indicate which companies were primary case companies.

Throughout our study, we collected empirical data from the workshops, and we took notes during informal discussions. It should also be noted that each of the workshops mentioned above involved *preparation meetings* in which we met with a subset of the participant group over video conferencing or on phone. In particular, this was the case in one of the primary case companies where the group we worked with included company representatives from the United States, from France, and from Sweden and where the planning effort was significant as the initiative we were invited to explore was of very high priority and involved key functions across the globe. For data analysis, we adopted an interpretive approach[41–43] as it provides useful advice and guidance for the coding process of empirical data. As part of our analysis, the preparation meeting and workshops notes, the interview transcripts, and all additional written documentation were carefully read by both authors of this paper in order to identify themes and concepts that were mentioned, experienced, and reflected upon by the company representatives we met with. In addition, and as a useful complementary source of information, whiteboard illustrations that were taken during the workshops were revisited with the purpose to add details and exemplify the workshop notes. During our analysis, we had the opportunity to continuously share and compare notes and discuss our interpretations also with the practitioners involved in the study. This combination of methodological techniques, empirical materials, and multiple perspectives allowed for added rigor, richness, and depth to our inquiry. As suggested by Walsham,[42] the generalizations that are made based on case study research are useful for other organizations that experience similar challenges in similar contexts. With the opportunity to work closely with a large number of companies in the embedded systems domain, we believe that the insights we provide, and the conceptualizations we develop, are valuable also outside the specific contexts of these companies.

Case companies and use cases

For the purpose of this publication, we have selected a set of primary and secondary cases as the foundation for the conceptualizations and generalizations we develop and present. As elaborated upon by Seawright and Gerring[44] and Gerring,[45] case study selection is critical as most case studies are about something larger than the case itself, even if the resulting generalization is issued in a tentative fashion. In case studies of this sort, the chosen case is asked to represent a population of cases that is often much larger than the case itself, and typically, background cases play a key role in analysis. Although they are not selected as primary cases per se, they are integrated into the analysis in an informal manner as they provide valuable input and relevant insights for the understanding and reporting of the object of study.

Following this line of reasoning, the empirical findings we report in this paper build on case study research in three companies that we selected as *primary cases*. It should be noted that in one of these companies, we studied three different use cases. All primary case companies are actively exploring the opportunities and benefits of digital assets and digital products. This involves concrete development and prototyping of new products and services, experimentation and evaluation with internal and/or selected (external) customers, and advanced analytics practices in order to validate whether new digital offering and/or business models have bearing.

TABLE A1 Data collection activities in the primary and secondary case companies included in the study

Activity	Company A*	Company B*	Company C*	Company D	Company E	Company F	Total number
Company-specific workshops	3	3	4	5	1	-	16
Interviews	1	2	-	-	1	1	5
Joint company workshops	All case companies invited (with the workshops being hosted at company and university sites)						8
Community workshops (PdM)	All case companies invited (with the workshop being hosted at one of the university sites)						1
Community workshops (senior leaders)	All case companies invited (with the workshops being hosted at company sites)						2

As *secondary cases*, and as additional background and input for analysis, we selected another three case companies that face similar challenges and opportunities as the primary case companies. It should be noted that after working closely with the 15 companies involved in the larger research initiative for close to a decade on topics related to digitalization of the embedded systems domain, the knowledge base for the conceptualizations and generalizations we make is significantly broader than the cases selected particularly for this publication. However, for the purpose of this paper, we chose to include only those companies with which we conducted the majority of our most recent research. As being on-site and maintaining daily or weekly contact with 15companies is not feasible, our research is organized so that we engage closely with four to six companies for each 6-month sprint. In this way, we get to work closely with all of the companies although not at the same time. Also, it provides the companies with the opportunity to adjust their level of activity in a certain project as they are typically engaged in more than one project at a time. Those companies that are a little less active during a certain time period are still involved and "listening in" by attending joint activities, reporting workshop, and community events.

The three primary case companies, and in which we studied a total of five use cases, are described below:

- *Company A*: A company manufacturing trucks, buses, and construction equipment as well as a supplier of marine systems. For the purpose of this paper, we studied three different use cases that all reflect the transition towards a digital company:
  - *Case A1 involves the development of future integrated services that will provide drivers with real-time information before, during, and after a trip*. As the basis for this information, data from external partners are collected and the idea is to build a platform where geographically distributed drivers can access onboard and offboard services. To achieve this, Company A has created an infrastructure in which third-party applications can be onboarded and a portal to which partners can be invited. When invited, external partners get access to the information they need, and they can add their own applications.
  - *Case A2 involves monetizing and sharing of data as Company A is experiencing a situation in which one of the suppliers has started requesting access to the data coming back from their component as well as more of the diagnostics data produced by Company A*. The supplier wants to use these data to improve the quality of the component they deliver by having access to performance data. For Company A, there are several incentives for sharing data with reliability being the most important. The the better components, the higher the reliability, and to achieve this, suppliers also need the data.
  - *Case A3 involves the development of a data-driven business model as Company A is actively exploring the opportunities to create a new business relationship with one of its suppliers*. This supplier is not a direct supplier, but Company A is buying systems in which components from this supplier are embedded. The supplier has limited experience in the automotive domain and has a different skill set compared with the direct suppliers that Company A works with. As one of these skills, the supplier is advanced in data analysis. Currently, this supplier is interested in getting access to data from Company A as this would help them improve the quality and the level of their service offerings to the automotive domain. The incentives for Company A are to help predict and assess quality in their products as sharing of data would enable the supplier to better understand the performance of their devices in the vehicles.
- *Company B*: A company manufacturing a broad variety of sports and utility vehicles. For the purpose of this paper, we studied *a use case in which the company is looking to introduce on-demand pricing of products and services*.
- *Company C*: A company developing products, services, and solutions for military defense and civil security. For the purpose of this paper, we studied *a use case in which the company is exploring the opportunities to introduce digital products with continuous capability growth* to reinvent their existing product portfolio.

In addition to the primary cases in which we studied a number of different use cases, we base our findings on long-term collaboration and insights from three secondary case companies. Throughout the paper, we use our experience from these case companies as additional background and input for analysis rather than as selected examples in detailing the empirical findings. The secondary case companies are listed below:

- *Company D*: A company developing a wide range of connected products for home appliances, for industry, and for transportation.
- *Company E*: A company providing information and communication technology (ICT) to service providers.
- *Company F*: A company providing processing and packaging solutions for food as well as services solutions for operation of plants.

APPENDIX B.

In the sections below, we provide the interview/discussion guideline that was used as the basis for our discussions with company representatives during workshop series and interviews. Throughout the study, and as the basis for our research, we used semi-structured interview questions grouped into a number of overall categories. For each category, we allowed the interviewees and the workshop participants to provide their input and insights as well as to add information they found important but that was not covered in the questions

The questions within each category worked as the foundation for discussing and reflecting on challenges as well as opportunities that the company representatives experienced as part of the digital transformation. Also, they helped in reflecting on current versus desired state of practices during times of rapid change. *It should be noted that the questions within each category were used as a basis for discussions rather than as a protocol for controlling the conversation.*

Digital transformation

- If looking at the digital transformation taking place across industries—how would you describe the key things/shifts that are happening in your domain/within your company in relation to:
  - Value creation and revenue streams
  - New technologies and new business opportunities
  - Product development, improvement, deployment and sales
  - Existing/new partners in the business ecosystem
  - What are the main challenges/opportunities you experience/foresee with regard to digital technologies and digital transformation of your business?

Product-centric versus service-oriented business models

- How would you describe your current ways of working with regard to business models?
- How would you describe the current interaction with customers before, during, and after sales?
- What are the main benefits with your current ways of operating with regard to product (and service) sales?
- What are the main drawbacks with your current ways of operating with regard to product (and service) sales?
- In what way/to what extent have digital technologies changed current ways of working with regard to product sales and customer interactions?
- Could you share an example(s) of a case where you have gone from selling a product (customers buy and own) to selling a service (customers having access)?
- Could you share an example(s) of a case(s) where you have gone from a physical offering to a digital offering?
- Could you describe the evolution when moving from product-oriented to service-oriented sales?

Data collection–use–monetization

- What do the data collection–analysis–use practices look like in the company?
- What type(s) of data is collected from products/systems and customers?
- How would you characterize the use of the data that are collected?
- Do you experience a shift in how data are used? If so, what drives this shift, what is it that is happening, and what is it that the company seeks to achieve with this?
- What are the current challenges involved in data collection–analysis–use?
- What are the current opportunities in data collection–analysis–use?
- With digital technologies being introduced, and with software and data becoming increasingly important, what are the new opportunities you are exploring?
- Are there examples of data-driven products/services in the company?
- To what extent (if at all) are data shared with suppliers and/or other partners?
- To what extent (if at all) are you able to monetize data?
- Could you describe a scenario(s) and/or a concrete example on data monetization with suppliers/external partners?
- Are there any examples of data being collected from your existing customers and monetized with new customers (multisided/two-sided market development)? If so, when did this start? What are the experiences so far? If not, is this something you aim for? What would be the opportunities you look for?

Introduction of new technologies

- How would you describe the technology evolution you experience in your company/industry domain?
- What role does software, data, and AI technologies play?

- What are the main challenges with the introduction of new technologies?
- What are the main opportunities with the introduction of new technologies?
- If looking at AI/ML/DL technologies, when/how/why were they introduced into your systems? What do they allow for and what opportunities do they open up for?
- In what way have AI/ML/DL technologies changed the way in which you use/exploit data?
- If looking ahead, what is the desired state in relation to AI/ML/DL technologies? What do you wish to accomplish that you could not accomplish before?

Business ecosystem

- In what way is digitalization of your business changing the existing business ecosystems in which you operate?
- Are there new partners being added to the ecosystem in relation to new technologies being introduced?
- What are the current challenges you experience in current collaborations with regard to digitalization of products and services?
- What are the current opportunities you experience in current collaborations with regard to digitalization of products and services?
- Could you share an example of a case where you have gone from a one-dimensional business model to a multidimensional business model (i.e., using data and AI solutions to allow for monetizing aggregated data coming from your original customers with a new group of customers in order to subsidize the original customers by offering the product at a lower cost)?

Continuous improvement/update of products/systems

- Could you describe the ways in which you work with product/system improvements/updates?
- Could you describe in what way current practices are changing due to connectivity, continuous deployment, practices, and so forth?
- To what extent (and in what parts of the system) are you able to do frequent and/or continuous improvements/updates?
- Are there ways in which you can continuously update mechanics and electronics components as well?
- In what way is continuous improvement/update practices allowing for new business models/opportunities?
- In what way is continuous improvement/update practices allowing for new customer relationships/interactions?